Abstract

Understanding the dynamics of premixed flames propagating during constant volume combustion is key to enhancing the performance of existing combustion devices, which provide 80% of the world’s energy supply, and reducing the impact of pollution on the environment. This work experimentally and numerically investigates confined premixed flame propagation in an initially quiescent mixture. Three combustion chambers are used; a curved wave disc engine channel and rectilinear channels of aspect ratio 7 and 10. The reacting mixture is methane/air and syngas (H\textsubscript{2}/CO)/air initially at atmospheric pressure and room temperature. The channel walls are assumed to be isothermal to incorporate the effect of heat transfer. For two-dimensional analysis, the reaction rate is modeled using both detailed and reduced kinetic mechanisms. The mass diffusion is investigated using three different diffusion models with different levels of approximation; the multicomponent diffusion model of Chapman-Enskog including the Soret effect; the mixture-averaged model without the Soret effect; and constant Lewis number. For three-dimensional analysis, a large eddy simulation coupled with the transport equation of the reaction progress variable is used. In this work, the reaction rate predicted using the Boger model of algebraic flame surface density is modified by incorporating a transient flame speed that accounts for the variation in the temperature and pressure of the unburned gases. The experimental measurements include
schlieren photography to track the flame structure and propagation speed, and the pressure-time history during the combustion process is measured by a pressure sensor mounted in the channel wall. The experimental measurements validate the numerical simulation results and provide further understanding of the flame and pressure dynamics. Unlike behavior previously reported in straight or 90° bend channels, premixed flame propagation in the wave disc engine channel exhibits different features: the convex tulip flame converts back into a concave flame and thus reveals the influence of channel geometry on flame evolution. The experiments show that the rate of pressure change eventually becomes negative mainly due to heat losses that engender a correspondingly slower flame propagation during the final stage of burning. The analysis of the numerical results reveals the effect of the interaction between the flame front, pressure field, and flame-induced flow on flame evolution during all stages of flame structure development. The results also demonstrate that both multicomponent diffusion with the Soret effect and the mixture-averaged model produce slightly different results in flame speed, structure, peak temperature, and average pressure for the methane/air mixture, while the deviation is more pronounced for syngas flames. The methane/air flame produced by the unity Lewis number model, however, lags behind its counterparts during early stages and dramatically accelerates, at which time the values of peak temperature and average pressure show unrealistic behavior. Furthermore, unity Lewis number flames develop an artificial second tulip flame after the first tulip flame is annihilated. This second tulip flame is neither observed in the Chapman-Enskog and mixture-average simulations, nor in the experiments. This reveals the role of the Lewis number in the intrinsic thermodiffusive flame instabilities and tulip flame formation. The three-dimensional simulation uncovers an interesting behavior for the flame structure that is introduced here as a “transverse tulip” flame, which has not been previously reported. The “transverse tulip” flame evolves in the direction perpendicular to that of the initial tulip flame after the latter undergoes the transition from cusped convex back to the concave finger shape. The commonly used Zimont model produces an unrealistically diffused flame front. The large eddy simulation coupled with the here-modified algebraic flame surface density overcomes this issue and reproduces the experimental observations of the flame structure, pressure-time history, and burning time with good agreement.